JANAIR

JOINT ARMY-NAVY AIRCRAFT INSTRUMENTATION RESEARCH

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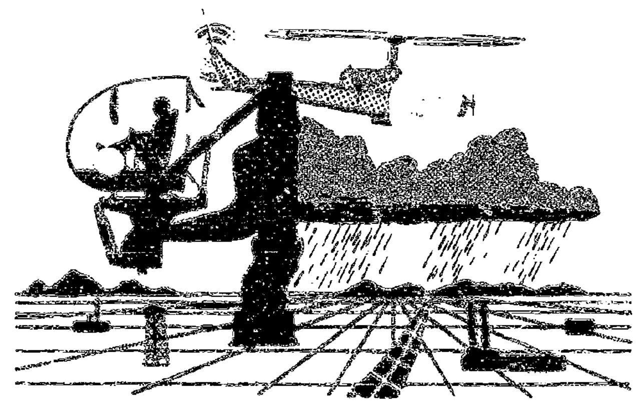

COMPARISON OF PERCEPTUAL WORK LOAD IN FLYING STANDARD INSTRUMENTATION AND THE CONTACT ANALOG VERTICAL DISPLAY

BELL HELICOPTER COMPANY

FORT WORTH, TEXAS

DIVISION OF BELL AEROSPACE CORPORATION • A textron COMPANY

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This report presents work which was performed under the Joint Army-Navy Aircraft Instrumentation Research (JANAIR) Project, a research and development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Material Command, the Office of Naval Research and the Bureau of Naval Weapons through an organization known as the JANAIR Committee. The Committee is currently composed of the following representatives:

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Mr. Len Evenson

The goals of JANAIR are:

a. The Joint Army-Navy Aircraft Instrumentation Research (JANAIR) project, is a research project, the objective of which is to improve the state of the art of piloted aircraft instrumentation.

b. The JANAIR Project is to be responsive to specific problems assigned, and shall provide guidance for aircraft instrumentation research and development programs.

c. The JANAIR Project will conduct feasibility studies and develop concepts in support of service requirements.

d. These efforts shall result in reports and the knowledge to form the basis for development of improved instrumentation systems, components, and subsystems.

ACKNOWLEDGMENTS

Any study utilizing equipment as complex as that utilized in this study requires a coordinated effort of a highly trained team of both engineers and human factors personnel. The final report of such a study is the documentation of the skills and educations brought to bear on an experimental problem by this team. It is the desire of the writers to thank herewith those persons who have contributed to a large extent to the successful completion of this study: Mr. Joseph Sgro, Mr. James Cavender, Mr. Ralph Absolom, Mr. Donald Swope.

ABSTRACT

The study reported in this document was an experimental approach to the comparison of visual free time that results in the pilot task when flying standard instruments and when flying the contact analog vertical display. The investigation was conducted under the direction of the Joint Army Navy Aircraft Instrumentation Research Program and funded under ONR Contract Nonr 1670(00). The standard instrumentation used in the study was an instrument panel composed of an airspeed indicator, an altimeter, a compass, an attitude indicator, a rate of climb meter, and a cross pointer position indicator. The contact analog vertical display investigated was built to Bell-JANAIR specifications by the Norden Division of United Aircraft Corporation for the JANAIR program. The task, performed in the Bell Helicopter Company dynamic flight simulator, required pilot Ss to fly a command altitude, heading, course, and airspeed. This was performed with both flight display systems. In addition, the pilot was required to read digits which were programed to appear on a separate display at varying rates. An index of the visual time available was obtained by the ability to read these digits in addition to performing the flight task.

Measures of performance included absolute integrated error scores of airspeed, altitude, heading and track deviations.

Results indicate that, in general, under the control condition (no digits) and the slowest reading rate condition (80 digits per 3 minute period) no statistically significant differences in performance scores existed on the two display panels. As the reading rates increased progressively to the fastest rate (360 digits per 3 minute period) performance, in general, on the vertical display remained relatively stable, while performance error scores on the standard instruments increased proportionately with increased reading rates.

A discussion of the results is included.

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I. INTRODUCTION

Flight by instrument flight rules (IFR) utilizing the standard flight instruments is one of the most exacting tasks in the repertoire of human performance. It currently involves the collection of data from a variety of flight instruments. These data are then interpreted through some cerebral mixing process and subsequently a relationship of the position and attitude of vehicle in three dimensional space is obtained and the pilot responds to this information.

The visual displays of the standard flight information on the instrument panel and the resulting mental picture are quite different. In order to formulate one from the other requires a time period up to several seconds. This changes with practice so that with experience the pilot is able to reduce it. Nevertheless, a time lapse exists which is of paramount importance in the precision of control of aircraft. During letdowns and "break outs" from an overcast the visibility at cloud base is often poor and visual reference with the ground is intermittent. In such a condition the pilot cannot forsake the instrument scanning technique and transfer to the full pictorial display of the contact world. If he does then these few seconds which it takes him to regain his IFR orientation in the event he re-enters IFR conditions causes him difficulty in navigation and control. Accident data indicate this as a distinct problem in flight. Experienced pilots know that partial IFR is not possible. To attempt it is to invite trouble.

The JANAIR flight instrument system was conceptualized and developed in the hope that the difficulty in interpreting the conventional displays, as outlined in the discussion above, could be reduced. The pictorial vertical display should present cues similar or identical to those used on flight by visual reference to the ground (visual flight rules, VFR). This type of display should then elicit performance which is fully learned or stereotypic of the pilot's normal flight responses. The perceptual shift or time lapse between two types of flight cues (VFR and standard IFR instruments) should be eliminated.

The literature indicates many advantages in this type of display. Grether, in 1947, indicated the superiority of pictorial displays over symbolic displays. Ritchie (1955) has defined and discussed the advantage, of an integrated display, i.e. one in which vehicle performance parameters. which are often segregated for display, are presented so that the operator may respond to the dual or multi-channel information with a single response movement.

If the pictorial displays incorporate such an "integrating" feature, then it may be rationalized that the time to interpret

the display and respond will be less with the pictorial display than that which is needed for the segregated information presentation.

The "real world" pictorial presentation of VFR flight may be interpreted as such an "integrated" display. The JANAIR contact analog may also be defined as such a display.

With a pictorial display it may be true that the experienced pilot does not have to respond to each individual presentation of information. He is not required to obtain his information in discrete places. He, therefore, may have additional or unused visual scanning time.

Some evidence is available to indicate that full use is made of the pilot's perceptual process with the standard IFR flight instruments. Studies have been conducted where eye movements of pilots were photographed in flight. Eye movements under a number of different conditions are reported by Fitts, Milton and Jones in a series of nine reports. Gainer and Rosinia (1962) later reported on pilot eye fixations in flying selected maneuvers using two different instrument panels.

The data from these studies indicated that there is a fantastically high frequency of cross checking necessary during all segments of standard instrument flight and very short eye fixations per instrument. The pilot's visual capabilities, in these conditions, are utilized completely.

A process of determining information sources and fixation time such as those reported would be impracticable with a pictorial display such as the JANAIR contact analog. The individual source of flight information was not so much of interest to this program as was the ability of the pilot to perform in an equal or superior fashion, thus to learn of his capability to receive other information or duties. This study was directed at answering such a question, i.e., what is the perceptual work load imposed on the pilot using the JANAIR flight display as compared with standard flight instruments.

II. TASK VARIABLES

The criterion imposed upon instrument flying requires the aircraft operator to assimilate a host of information displayed before him on an instrument panel reflecting the aircraft's momentary situation. The manner in which this information is utilized varies from one flight maneuver to another as does the visual scanning pattern and the time required to assimilate information.

When an effort is made to evaluate selected instrument display systems for flight capabilities, assumptions of display validity are interpreted from the flight performance measured on selected flight tasks that are representative. In this study a cruise or straight and level task was selected. Performance data on two display configurations were collected until equality was indicated. Display effectiveness was then measured on the ability to maintain performance and accept additional task loads.

Basic Task Criterion

The selection of a realistic criterion for instrument flight standards for display evaluation is somewhat arbitrary. A number of factors must be considered, among which are: (1) the level of training of the Ss, (2) amount of prior instrument time brought into the experiment by the Ss, (3) difficulty in the control of the vehicle (either inherent or imposed by forcing functions), etc. In order to satisfy a realistic criterion, the F.A.A. standards for an instrument flight rating were selected. These stipulate that proficient performance in the maintenance of certain flight parameters must be met before instrument flight standards have been satisfied. The Federal Air Regulations fo demonstration of aeronautical skill for straight and level flight on instruments is performance within ± 10 degrees of proper heading, ± 100 feet in altitude and ± 10 knots in airspeed (Flight Instructors Handbook). In the present study pre-test data indicated that Ss could control the simulated aircraft within the prescribed limits of ± 5 degrees of proper heading, ± 50 feet altitude and ± 5 knots airspeed. This criteria was therefore selected. Ss were required to meet it using both the standard panel and the JANAIR flight display. The criteria for this study was thus more stringent than F.A.A. minimums.

Prior to the experiment proper, the Ss practiced the task until they were consistently performing within the criterion for altitude, airspeed, heading and track on each instrument display system. Track on the vertical display was presented in the form of a flight pathway. On the standard instrumentation system it was presented on a cross pointer position meter. The criterion limit for each display system was ± 50 feet lateral deviation from the desired track.

Once proficiency was demonstrated by each S on the basic task of holding altitude, airspeed, heading and track, he was considered trained to participate in the experiment proper. Demonstration of proficiency was ascertained by requiring each S to perform three consecutive 3 minute trials within the criterion limits on each of the parameters on each instrument display system.

Digit Reading Rates

In evaluating standard instrumentation with the contact analog it was necessary to devise a quantitative method for measuring the visual free time which the Ss could devote to an additional task while performing the basic instrument flight task. Several possibilities of an additional task to be performed were examined. A method was needed which would require exposure for each S and would not permit the S to draw upon learned word formation. The method selected required the Ss to read unitary digits, presented in a random fashion on a "nixie tube" at various rates. On each of the various reading rates exposure time was held constant at [illegible] seconds. The various reading rates were defined as the interval between the presentation of the digits. The total number of digits to be read during a 3 minute trial was thus a function of the interval of time between the presentation of the digits.

The various reading rates were as follows.

Condition	Interval Between No. (Sec.)	Total No. Presented Per Trial
A	-	
B	1.75	80
C	1.0	120
D	.4	200
E	0.0	360

Condition A served as a control condition in which no digits were presented.

III. EXPERIMENTAL APPARATUS

The experiment was conducted in the Bell Helicopter Company Flight Simulation Laboratory using the dynamic flight platform which was programed to simulate helicopter motion characteristics in pitch, roll, yaw and "heave". The equations of motion used in the study represented the movement of a Bell UH-1A helicopter. An analog computer provided driving signals from the servo actuator of the simulator platform.

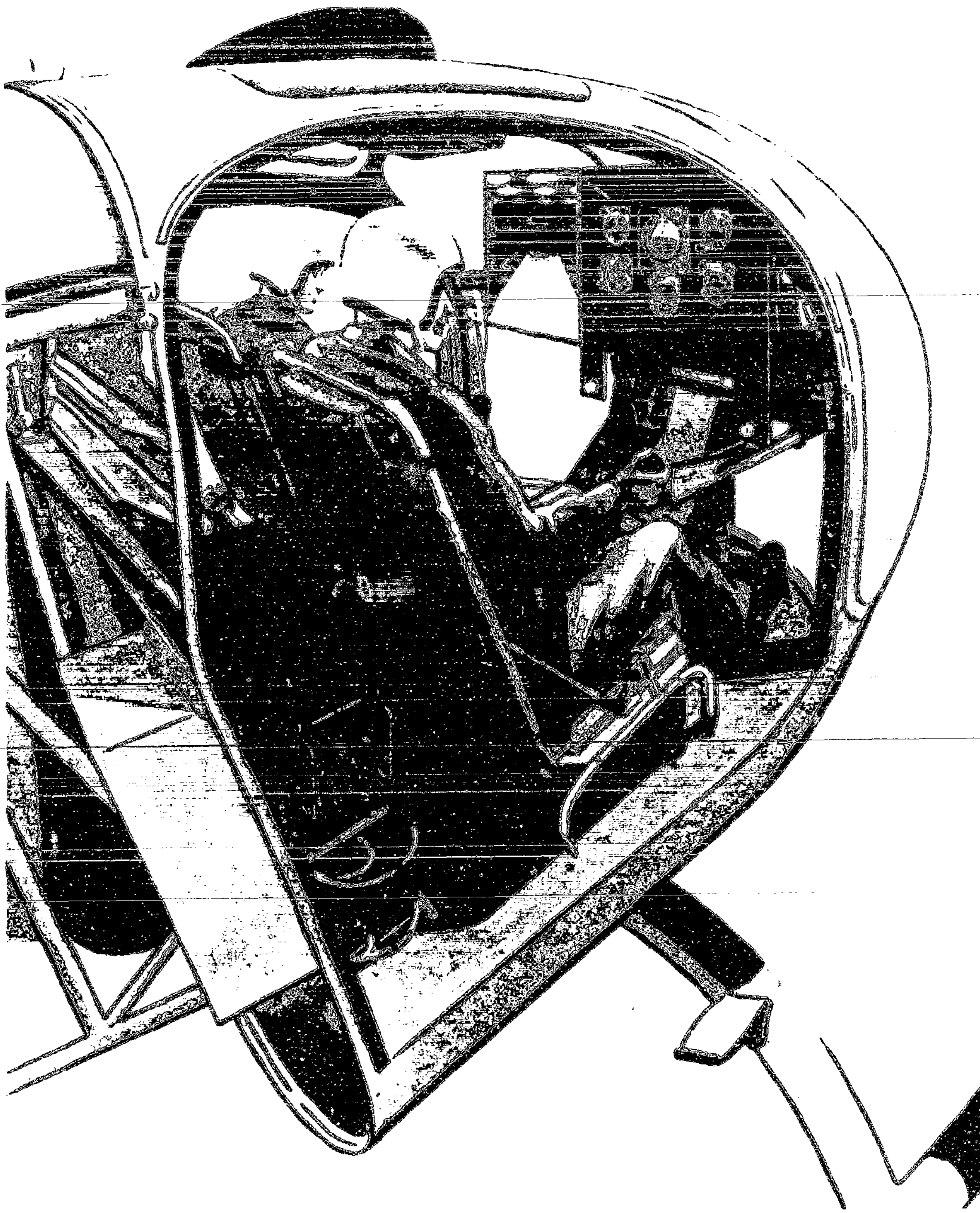
The simulator cabin was equipped with two pilot's seats, situated laterally adjacent to each other. Each seat was provided with a collective control, cyclic stick and foot pedals. The controls were conventional in configuration, placement and function. The simulator cabin also possessed the features of cabin vibration and engine and rotor noise.

Detailed descriptions of the platform are found in Willis (1960, 1962) and Fedderson (1962). The equations of motion were derived from Air Force Flight Test Data (Caldron and Balfe, 1960) and reported by Kelley (1963).

A. The Contact Analog Vertical Display

The vertical display used in the study was a pictorial encodement of the real world. The display signal generator system, described in a Norden Technical Report (1963), provided a variety of inputs in video form to the cockpit display. Computed attitude information in pitch and roll were displayed in the form of an earth stabilized horizon. The transformation of earth coordinate positions into appropriate display screen coordinates were computed utilizing velocity signals integrated to provide position of the grid. From these signals to the grid plane, information with regard to heading, translation and altitude could be presented. A flight pathway could be displayed utilizing position signals computed external to the Norden unit. The pathway was displayed as an earth stabilized roadway. Perspective cues presented it as a 24 foot wide pathway terminating at infinity.

The cockpit display was a 17-inch television monitor which was masked to provide a 12 by 12 inch image. At a normal viewing distance of 23 inches this represented a 30 by 30 degree field of view. The vertical display television monitor was located in front of the left seat in the cabin and positioned so that the horizon line of the display was situated at eye level when S effected a zero pitch angle. Figure 2 shows the contact analog vertical display installed in the left hand position of the dynamic flight simulator. No auxiliary instruments were provided in conjunction with the vertical display for quantitative flight information.



Sketch of cabin of dynamic pl-tform simulator showing contact analog display at left and standard instrument display at right

Figure 1.

Command altitude was referenced to the pathway which was programed 1000 feet above the grid plane. The S, by keeping the pathway in its initial condition, could maintain proper altitude. Airspeed was held at a constant 80 knots by reckoning the closing rate of the pathway tarstrips and by maintaining the appropriate pitch down attitude. A command heading of zero degrees was maintained by keeping the pathway aligned to the center of the display. Course deviation was indicated by displacement from the near end of the pathway to the right or left. Limits of pathway saturation were ± 300 feet in the lateral plane and ± 100 feet in the vertical plane. Beyond these limits the pathway remained at the limit value. The equation for helicopter velocity along the pathway was $V_A = V_N \cos\beta + V_E \sin\beta$

where V_N = north component of velocity,
V_E = east component of velocity, and
β = command (pathway) heading.

B. Standard Instrument Display

Figure 1 shows the standard instrument display installed on the right side of the simulator cabin. Included on the standard instrument panel were the following instruments:

(1) Airspeed
(2) Attitude gyro
(3) Altimeter
(4) Cross pointer position
(5) Directional gyro
(6) Rate of climb.

The same analog voltage used to drive the vertical display pathway tarstrips was used to drive a panel meter labeled airspeed. This voltage was proportional to helicopter velocity along the pathway as opposed to velocity along the helicopter heading.

The artificial horizon on a Lear Model 4005G remote attitude indicator reproduced the same information in pitch and roll that was presented on the vertical display. This indicator was designed for synchro inputs. Since pitch and roll information was available in a d-c analog voltage form, it was necessary to process these data in a modulator. The resulting a-c synchro signals were applied to the Lear Model 5405G attitude indicator amplifier and thence to the indicator. The scale factor used in both attitude channels was 100 volts/radian.

Altitude data on the standard instrument panel was displayed on a standard three pointer altimeter. An analog voltage of 64 feet per volt was the driving force.

Vertical and lateral deviation data were reproduced on the standard instrument panel by an ID453 indicator which is normally used in an instrument landing system. The vertical

needle on the instrument indicated lateral deviation (right or left) from the pathway. It was driven to full scale by a deviation from the pathway of ±50 feet, either laterally or vertically.

Heading information was displayed by a radio compass indicator, which in turn, was driven by a synchro signal from the computer. Limits of heading change were 540 degrees from the initial position.

Rate of climb was displayed on a panel meter calibrated in hundreds of feet per minute.

C. Numerical Readout Device

A numerical readout device (Burroughs "Nixie" Tube) and a display warning indicator (incandescent pilot lamp) were installed on the lower right hand corner of each panel 14 inches to the right and 14 inches below the center of each display array. These may be seen in Figure 1. The displacement of the indicators ensured that the Ss' field of vision be shifted to read the numbers presented on the indicator. The nixie tubes were 1/2 inch in diameter and displayed 3/8 inch numbers. An equipment description of the random number generator is found in Appendix A.

IV. SUBJECTS

Ten Ss participated in the experiment. All were employees of Bell Helicopter Company. Each S was either a helicopter or fixed wing pilot or had extensive previous experience in performing tasks in the dynamic simulator. Each was thoroughly familiarized with both the contact analog vertical display and standard instrumentation and was proficient in operating the dynamic simulator.

V. PROCEDURE

A. Task and Training

Prior to the initial training trial on each display the vertical display (VD) and the standard instrument panel (SI), instructions (Appendix B) were read to the S, stating that the purpose of the experiment was to determine the visual free time afforded by each display while performing a tracking task maintaining 0-degree heading, 80 knots airspeed, 1000 feet altitude, and course along a given flight path. Each trial was initiated with controls positioned for the proper airborne attitude under these simulated flight conditions.

During the training or pre-test phase, each S was trained on three minute trials until he performed the tracking task within a predetermined criterion on three successive trials on each of the two display systems. The criterion was established on the basis of modified FAA instrument flight standards, pre-test findings, and computer scoring capabilities, and is as follows:

Parameter	Task Requirement	Tolerance
Airspeed	80 knots	$\pm$5 knots
Altitude	1000 feet	$\pm$50 feet
Heading	0 degrees	$\pm$5 degrees
Flight Path	On pathway	$\pm$50 feet (lateral)

Ss were informed when they had reached the desired level of proficiency and were sufficiently trained to enter the testing phase of the experiment.

B. Design and Test Sessions

Two test sessions, each consisting of 10 three minute trials were conducted for each subject. Prior to the first session, instructions (Appendix C) were read to the S which emphasized a primary task of reading a series of numbers presented at a given rate on a nixie tube located at the lower right of the console panel.

The rates were exhibited to the S for a period of 30 seconds to familiarize him with the various time intervals and the exposure time of the numbers. The S was requested to read the numbers so as to be audible to the E. The primary task of reading each and every number was re-emphasized to the S and he was asked if there were any questions. The first trial of each session was a "warm-up" to re-establish a feel for the system's dynamics. No numbers were presented during this practice trial. Following this, five test trials were run on one of the displays, e.g., the vertical display, in a pre-determined sequence for rate presentation.

Thereafter, five trials were run on the other display, in this case the standard instruments, with this sequence reversed. The second test session was designed to counterbalance the display presentation of the first session while maintaining the reversed sequence of rate presentation as set forth in Session 1.

In this manner, a counterbalanced sequence for rate presentation and display presentation was established. The foregoing explanation is illustrated, by S, in Table 1. This counterbalance of presentations was introduced to minimize the effects of practice and fatigue on performance. A two minute interval between trials allowed the E time to record performance scores, note reading errors and instruct the S in repositioning of controls for the next trial. The display not being utilized was disengaged and panel lights turned off. Information pertaining to individual performance was withheld from the S until completion of testing.

C. Measures of Performance

Deviations from the standard were recorded as absolute integrated errors. These scores were reflected as numeric scores and were read directly from five channels of the integrator: airspeed, altitude, heading, lateral right and lateral left. If, in reading the various rates, the number of errors exceeded 10 per cent of the total numbers presented, the data acquired were considered invalid. This condition occurred only once and was rectified by rerunning the S on the trials in which his errors were excessive.

D. Method of Analysis

The four dependent variables were subjected to statistical tests of significance. The method employed was the parametric multiple analysis of variance from which an F test could be computed. For the main effects of displays and reading rates which yielded significant F ratios, Duncan's New Multiple Range tests were computed to test for significance of factor differences (Edwards, 1960).

Table I. Order of Presentation of Test Conditions

Day 1

Subject No.	Display	Trials 1	2	3	4	5	Display	Trials 1	2	3	4	5
1	VD	A	B	C	D	E	SI	E	D	C	B	A
2	SI	B	C	A	E	D	VD	D	E	A	C	B
3	VD	C	D	E	A	B	SI	B	A	E	D	C
4	SI	D	E	B	C	A	VD	A	C	B	E	D
5	VD	E	A	D	B	C	SI	C	B	D	A	E
6	SI	E	D	C	B	A	VD	A	B	C	D	E
7	VD	D	E	A	C	B	SI	B	C	A	E	D
8	SI	B	A	E	D	C	VD	C	D	E	A	B
9	VD	A	C	B	E	D	SI	D	E	B	C	A
10	SI	C	B	D	A	E	VD	E	A	D	B	C

Day 2

Subject No.	Display	Trials 1	2	3	4	5	Display	Trials 1	2	3	4	5
1	SI	E	D	C	B	A	VD	A	B	C	D	E
2	VD	D	E	A	C	B	SI	B	C	A	E	D
3	SI	B	A	E	D	C	VD	C	D	E	A	B
4	VD	A	C	B	E	D	SI	D	E	B	C	A
5	SI	C	B	D	A	E	VD	E	A	D	B	C
6	VD	A	B	C	D	E	SI	E	D	C	B	A
7	SI	B	C	A	E	D	VD	D	E	A	C	B
8	VD	C	D	E	A	B	SI	B	A	E	D	C
9	SI	B	D	E	C	A	VD	A	C	B	E	D
10	VD	E	A	D	B	C	SI	C	B	D	A	E

VI. RESULTS

The results of the experiment are presented in the form of Absolute Integrated Errors (AIE) of command heading, altitude, airspeed and course. Parametric analyses of variance were run on each of the four dependent variables to test for treatment mean differences for each Displays and Reading Rates and the interaction of Displays and Reading Rates. The number of observations were equal in each of the various treatment groups. The main effects of Displays and Reading Rates were submitted to F tests for over-all mean differences. The F test being very insensitive to non-normality and with equal N's being also insensitive to variance inequalities, violations of the assumption of homogeneity were ignored as possibly affecting the sensitivity of the F test (Box, 1953).

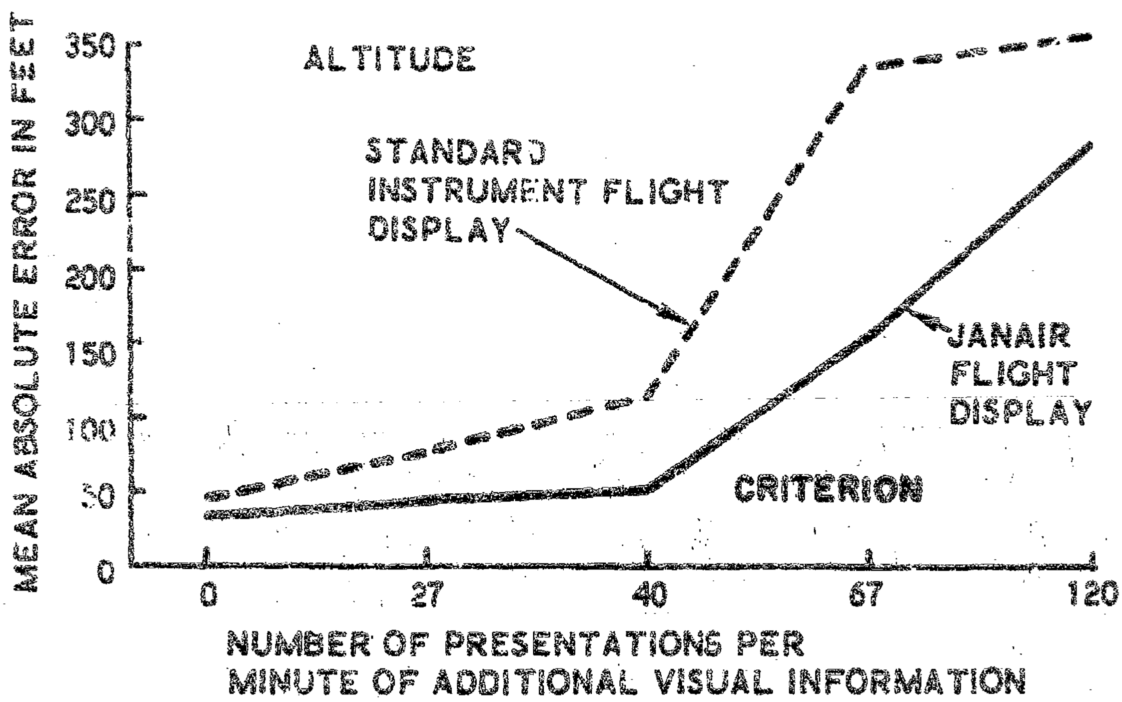
In each case where an F ratio was computed, the over-all treatment mean differences were accepted as significantly different if the .01 level of confidence was achieved, i.e., the acceptance of chance occurrence of the treatment mean differences was restricted to one time in 100. In those cases where a significant F ratio ($P \geq .01$) was found in the analysis of variance, a Duncan's range test was computed to test for individual treatment mean differences. Again, the .01 level of confidence was accepted as reflecting significant mean differences for each of the mean comparisons, thus restricting a chance occurrence of the mean differences to one time in 100.

The following results were obtained.

1. Altitude - Figure 2 is a graphic representation of the mean AIE of altitude. It can be seen that under 0 Reading Rate, where no digits were presented (RR-0) that performance on VD and SI was relatively close but as the reading rates increased, the AIE on both VD and SI increased. The increase in errors tended to be greater on SI than on VD.

Results of an analysis of variance run on the altitude errors are found in Table I, Appendix D. The analysis revealed that the over-all mean differences in Rates were statistically significant at the .01 level of confidence. The over-all main effects of Displays was not significant nor was the interaction effects.

Since the F ratio altitude errors under Displays did not approach the .01 level of significance, the mean errors of VD and SI under each of the five reading rates were summed together. The summed mean errors for the five reading rates were submitted to the Duncan's multiple comparison test. To apply the test the reading rate means were arranged in the order of magnitude, as in Table I, Appendix E. Mean differences were then compared with the significant ranges which were determined by multiplying each significant studentized range with the standard error of the mean.



Mean absolute error of altitude for SI and VD under five conditions of numeric presentations per minute of additional visual information

Figure 2.

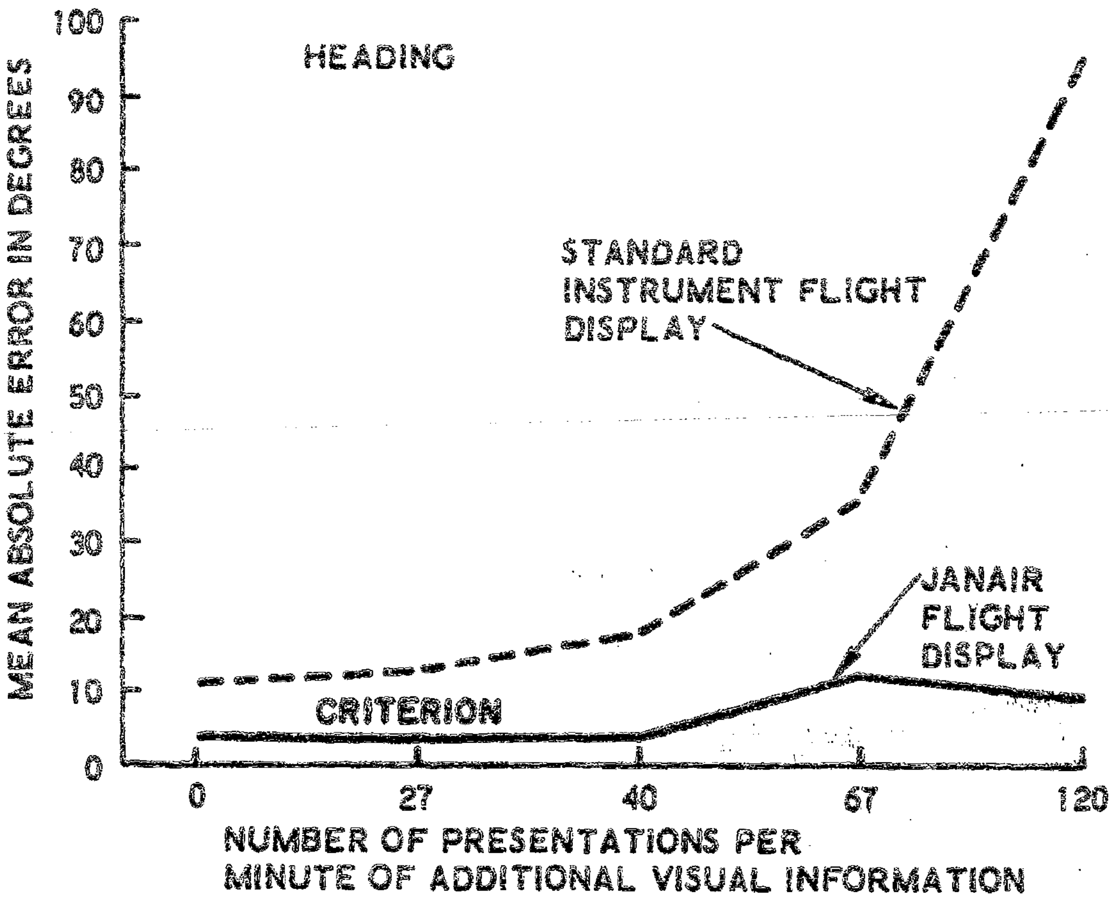
The formula used for computing the standard error of the mean was $S_{\bar{x}} = \frac{S}{n}$

where S is the square root of the error mean square of the analysis of variance, and n is the number of observations on which the mean is based.

It is seen from Table I, Appendix E, that rates 0, 80, and 120 did not differ significantly from one another, nor did rates 200 and 360. The only significant increase in altitude errors occurred thus when going from a reading rate of 120 digits per 3 minute trials to reading 200 digits per 3 minute trial.

2. Heading - The mean errors of heading for SI and VD under the five reading rates are plotted in Figure 3. The plot shows that heading errors were less on VD under each of the five rates. The plot also reveals that increases in the heading error on SI were proportionately greater than the increases in error on VD.

The mean errors of heading for the ten Ss were submitted to an analysis of variance. The summary of analysis of variance for heading is shown in Table II, Appendix D. Over-all effects of Displays and Rates, it is seen, were each significant at the .01 level of confidence. Also, a significant interaction effect was revealed by the analysis.



Mean absolute error of heading for SI and VD under five conditions of numeric presentation per minute of additional visual information

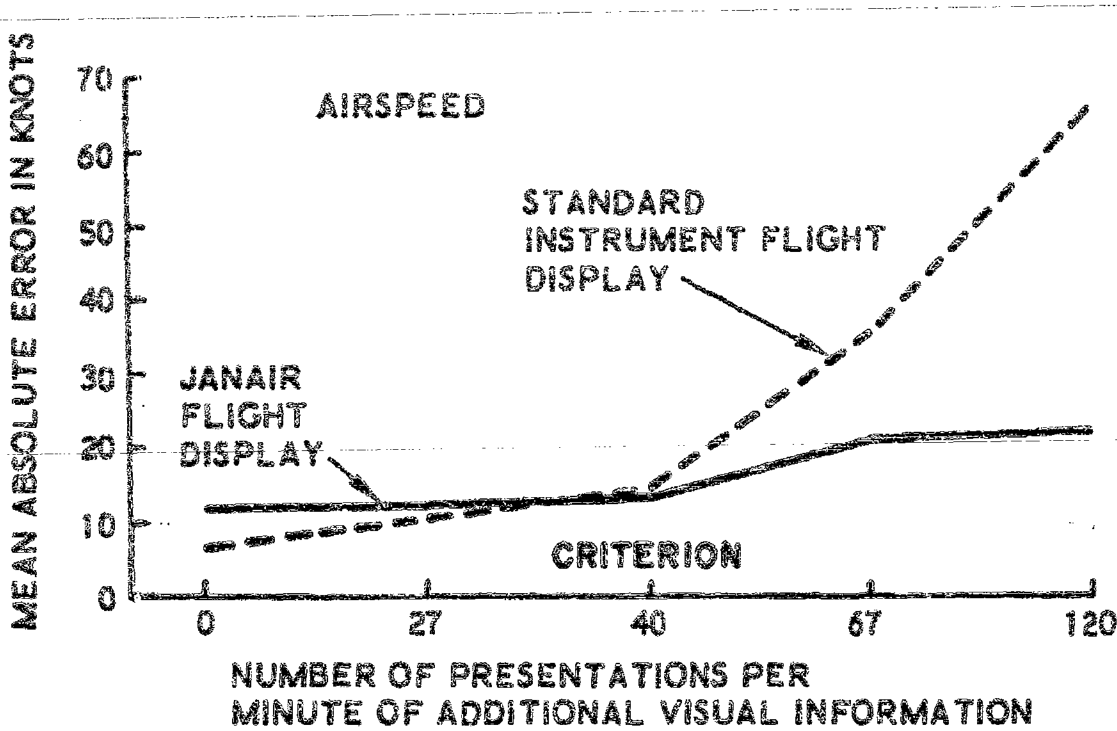
Figure 3.

The ten individual treatment means of heading error were arranged in the order of magnitude and the Duncan's range test applied. The test for mean differences is found in Table II, Appendix E No significant differences were found to exist in mean heading errors of VD for the 10 Ss under Rates 0, 80 and 120, nor under Rates 200 and 360, but a significant increase was found in the heading errors when going from Rate 120 to 200. There were no significant differences in heading error on SI under Rates 0 and 80, but Rates 120, 200 and 360 were each statistically different.

3. Airspeed - A graphic representation of the mean airspeed errors for ten Ss is found in Figure 4 . It is seen that under Rates 0 and 80 the airspeed error was greater on VD but under Rates 120, 200 and 360 the airspeed errors became greater on SI. It is also seen that the increase in errors was proportionately greater for the SI than for VD as Rates increased.

The summary of an analysis of variance for the airspeed is found in Table III, Appendix D . The analysis reveals that Displays, Rates and the interaction of Displays and Rates were each statistically significant at the .01 level of confidence.

The Duncan's test was applied to the mean airspeed errors. The results of the test are shown in Table III, Appendix E.



Mean absolute error of airspeed for SI and VD under five conditions of numeric presentations per minute of additional visual information

Figure 4.

The results of the test are as follows:

(1) The range of means including SI - 80, VD - 0, and VD - 80 was significantly greater than SI - 0.

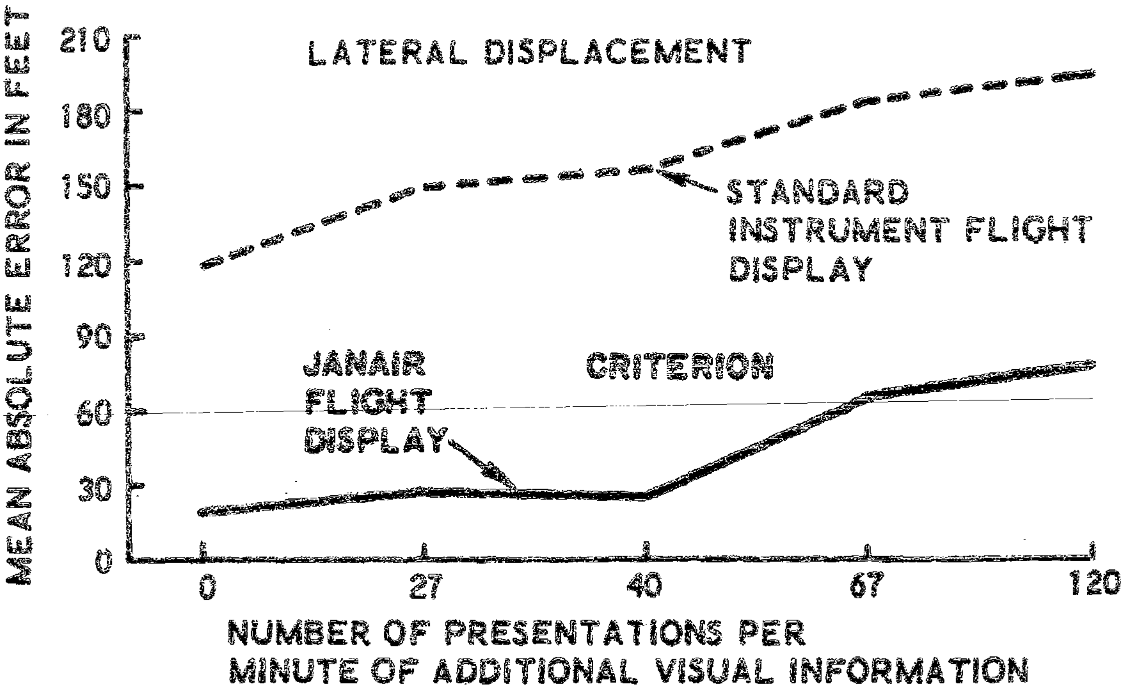
(2) The ranges of means revealed VD - 0 and VD - 80 were not significantly different, but SI - 80 was significantly less than VD - 120.

(3) The ranges of means showed VD - 80 and VD - 120 to be non-significant, and VD - 120 and SI - 120 to be non-significant, but that VD - 80 was significantly less than SI - 120.

(4) The means of VD - 200, VD -360, SI - 200 and SI - 360 were each significantly different when compared with every other condition.

4. Track - Track mean errors of the ten Ss' performance on SI and VD, as they were affected by Rates, are found in Figure 5. It may be noted that considerably greater track errors were recorded on SI under each of the five reading rates.

To test for the statistical significance of the differences in displays and rates the track mean errors were submitted to an analysis of variance. A summary of the analysis is shown in



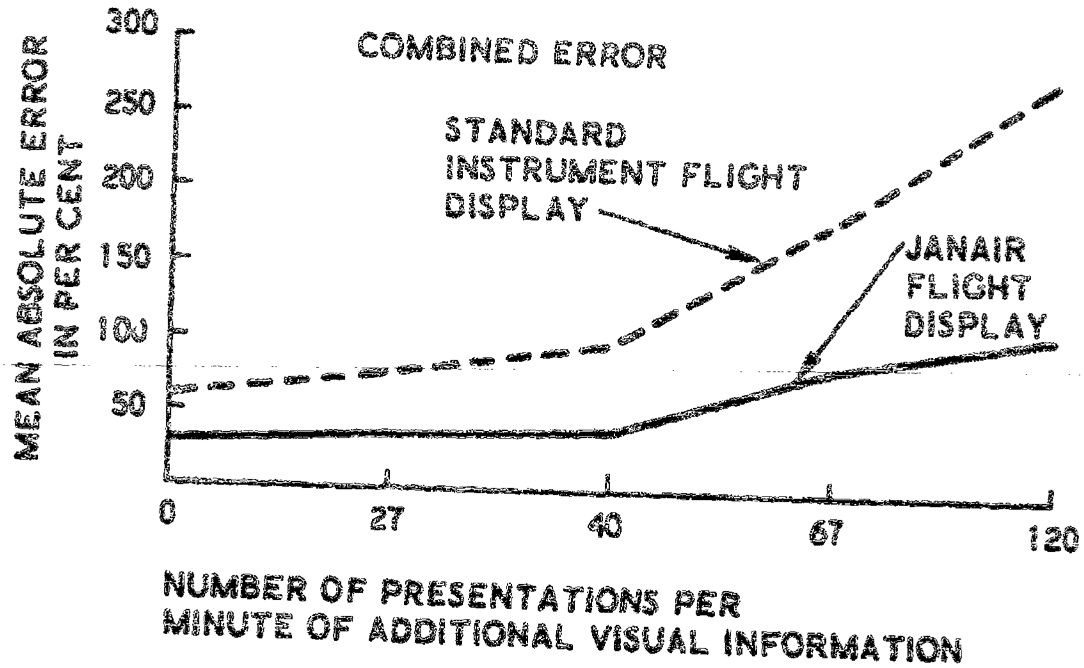
Mean absolute error of lateral displacement for SI and VD under five conditions of numeric presentations per minute of additional visual information

Figure 5.

Table IV, Appendix D. Main effects of both Displays and Rates, it is seen, exceeded the .01 level of confidence for over-all mean differences. No significant interaction was revealed by the analysis.

A Duncan's test of the track mean errors on the two displays under five reading rates is found in Table IV, Appendix E. The test revealed that all conditions of track errors were significantly different at the .01 level of confidence except in the comparison of VD - 80 with VD - 120 which was not significantly different at the same level of confidence.

5. Combined - A combined error score was computed by summing a proportional error score in each cell for altitude, heading, airspeed and track. The proportional error of each parameter was obtained by dividing the individual error scores in each cell by the over-all mean for that parameter. This provided a standard base line for weighting the errors contributed by each of the four dependent variables. The combined error thus provided as over-all index of performance on each of the two displays under five reading rates. The results of combining the four dependent parameters is graphically illustrated in Figure 6. It may be noted that the combined mean errors were always less on the VD under the five rates and that the increase in errors as a function of rates was proportionately less on VD.



Mean absolute error of combined error score for SI and VD under five conditions of numeric presentations per minute of additional visual information

Figure 6.

To assess the significance of these differences, the combined mean errors were submitted to F tests for Displays, Rates and the interaction of Displays and Rates. The results of these tests are found in Table V , Appendix D. The over-all main effects of both Displays and Rates were revealed to be significant at the .01 level of confidence. It is also noted that the F test produced a significant interaction effect of the mean combined errors.

Once again, the Duncan's multiple range test was applied to the 10 treatment means of the combined mean errors of VD and SI under five reading rates to test for the range of mean differences. The results of the test are found in Table V , Appendix E. No differences were revealed among the mean errors for VD under the five reading rates. For SI errors, it was found that Rates 0, 80 and 120 were not significantly different, and Rates 120 and 200 were not significantly different; however, Rate 200 was significantly greater than Rate 0 and Rate 360 was significantly greater than Rate 200.

Summary of Results

Table 2 is a summary table of the results of comparing SI and VD mean error differences under each of five reading rates. The table reveals that Rates produced no significant differences in comparing altitude errors on VD with altitude errors on SI.

Table II
COMPARISON OF SI AND VD ERROR DIFFERENCES
UNDER EACH OF FIVE READING RATES

	0	80	120	200	360
Altitude	NS	NS	NS	NS	NS
Heading	SI*	SI*	SI*	SI*	SI*
Track	SI*	SI*	SI*	SI*	SI*
Airspeed	VD*	NS	NS	SI*	SI*
Combined	NS	NS	NS	SI*	SI*

* Indicates Significance .01
NS Indicates Non-significance

Both heading and track mean errors were consistently greater on SI for the five reading rates than on VD. Airspeed error, it may be noted, was significantly greater for VD errors under Rate 0, non-significantly different on Rates 80 and 120, and significantly greater on SI under Rates 200 and 360. It is seen that the combined mean errors were significantly greater on SI under Rates 200 and 360 than the VD mean errors under the respective rates.

Table III
COMPARISON OF INCREASED READING RATES
AS REFLECTED BY SI AND VD ERRORS

	Rate Comparisons			
SI Errors	0 vs 80	80 vs 120	120 vs 200	200 vs 360
Altitude	NS	NS	200*	360*
Heading	80*	120*	200*	360*
Track	80*	120*	200*	360*
Airspeed	80*	120*	200*	360*
Combined	NS	NS	NS	360*
VD Errors				
Altitude	NS	NS	200*	360*
Heading	NS	NS	200*	NS
Track	80*	NS	200*	360*
Airspeed	NS	NS	200*	360*
Combined	NS	NS	NS	NS

* Indicates Significance .01
NS Indicates Non-significance

Table 3 is a summary of the effects of increased reading rates of mean errors for each SI and VD. Inspection of the table shows that the trend of the results on SI was generally to have significantly greater error as reading rates increased from 0 to 360. On the other hand, it may be noted from the table that the results on VD errors was relatively unaffected by an increase in Rates 0 to 120 with a general increase in error occurring at Rates 200 and 360.

VII. DISCUSSION

The results of this study may be considered as a very preliminary examination of the visual work load imposed upon the pilot by two different types of flight displays, the pictorial display (the JANAIR display) and a series of symbolic or semi-symbolic displays (standard instrument flight displays). Only one maneuver was examined but the results indicate that a continued effort in this direction might be expeditious. The distinct superiority of the pictorial display was indicated. This superiority was not in terms of improved performance since this was not the direction of the study. It was instead in terms of the amount of visual free time permitted with one display over that permitted by another when performance was equal.

The interpretation of the phenomena which permitted these results leads in three directions. The first thesis that might be proposed to explain this suggests that the instrument pilot, when using a pictorial instrument display, operates like the VFR pilot, thereby performing with a combination of information which samples both general and specific flight performance data. Standard symbolic displays present only specific or quantitative information. The type of display array currently used for instrument flight requires continuous and rapid shifting of the eyes in order to maintain a semblance of continuous monitoring of each desired flight performance parameter. Since these displays are of a quantitative nature, they require a complex series of mental processes, i.e., time to be read, to be recorded and to be interpreted. It is logical, therefore, to assume that the perceptual channel soon becomes loaded with this method of monitoring. On the other hand, with a pictorial display a pilot may select qualitative or quantitative information. A large amount of his visual checking time may require only generalized or qualitative data. From standard instrumentation it is not possible to achieve this information; with the pictorial display this is possible. It may be assumed that the pilot can assimilate the pictorial qualitative information more quickly than its counterpart.

A second thesis suggests that with the JANAIR type display the pilot may accumulate information on more than one flight parameter at a glance. This again should be saving in terms of loading the visual channel.

The third possible explanation for the superiority of the JANAIR pictorial display may be that it is configured in such a manner that it may be viewed in the peripheral viewing area. Foveal vision is not necessarily required. The additional visual task which was required in this study in order to estimate visual overload was presented in a remote corner of the instrument panel in both instrument displays. It was found that peripheral

monitoring of the JANAIR display was possible when foveal vision was attending the secondary display.

The end result may thus be that the pictorial JANAIR display does not require the same amount of scanning time or visual channel loading as do standard IFR displays in order to maintain a continuous awareness of each of the flight parameters with a subsequent equal performance.

The data indicate a strong difference between the two displays as the additional visual load increases. Significant differences were indicated between the two display conditions for certain performance measures when <u>any</u> additional visual task was imposed. This difference increased to include almost <u>all</u> performance measures as the visual work load was increased to the maximum tested. As the visual load is increased on the standard panel, performance decrement is significant between presentation rates. This was not the case with the JANAIR display.

The results of this study indicate that further attention should be directed to the questions: (1) What effect does increased visual load have on other maneuvers? (2) Can the display be improved to permit even better performance with additional visual load? (3) How can the definition of visual work load be improved? and (4) What is the extent of utilization of the visual field when employing the JANAIR display?

VIII. SUMMARY

The study reported in this document compared two instrument panels (the JANAIR vertical display and the standard instrument flight display) in terms of the amount of visual free time which was available when performance using these two displays was equal.

The task was performed in the JANAIR Bell Helicopter Company dynamic flight simulator. Pilots were required to fly a straight and level course maintaining altitude, heading, track and airspeed. A forcing function introduced a rough air component to this task. Performance on both displays was equated in a testing period. Criterion was equal to or better than F.A.A. standard instrument flight criterion. The subjects were then tested to determine their free visual time. This was achieved by introducing a secondary visual task which required an oral reading of numbers. These were presented at rates varying from zero to two per second. Performance measures included: deviations from the standard or prescribed airspeed, altitude, heading and track in terms of integrated absolute error.

Results indicated that the pictorial JANAIR display was by far the superior display as the visual work load increased. This was reflected in the decrement of performance on the primary flight or visual task. The performance using the vertical display remained relatively stable while that of the standard instruments decreased proportionately with the increased reading rate.

It is hypothesized that these results are due to three factors. First is the utilization of qualitative information. This apparently requires more mental processing than does interpretation of standard instrumentation. Second is the integrated presentation of more than one flight performance parameter. Third is the ability of the pilot subjects to read the JANAIR vertical display with peripheral vision.

The results suggest that additional information is desirable in terms of extent of perceptual work load which can be assigned to the pilot when using the JANAIR flight displays.

IX. REFERENCES

Bamford, H.E., Jr. and Ritchie, M.L. Integrated Instruments: A Roll and Turn Indicator. WADC TR 57-205, 1957.

Box, G.E. Non-normality and Tests on Variances. Biometrica, 1953, 40, 318-335.

Caldron, J.M. and Balfe, P.L. HU-1 Stability and Control Evaluation. AFFTC-60-57, ARDC, Air Force Flight Test Center, Edwards Air Force Base, California, December 1960.

Edwards, A.L. Experimental Design In Psychological Research. Rinehart and Company, Inc. 1960.

Fedderson, W.E. The Role of Motion Information and Its Contribution to Simulation Validity. Bell Helicopter Company ANIP Technical Report No. D228-429-001, April 1962.

Fitts, P.M., Jones, R.B. and Milton, J.L. Eye Fixations of Aircraft Pilots, III. Frequency, Duration and Sequence Fixations when Flying AF Ground-Controlled Approach System (GCA). USAF TR 5967, December 1949.

Fitts, P.M. Jones, R.B. and Milton, J.L. Eye Movement of Aircraft Pilots During Instrument Landing Approaches. Aero Eng. Rev., 1950, 9, 1-16.

Fitts, P.M. and Simon, C.W. The Arrangement of Instruments, the Distance Between Instruments and the Position of Instrument Pointers as Determinants of Performance in an Eye-hand Coordination Task. USAF AMC TR 5832, 1950.

Flight Instructors Handbook, TM 105, Federal Aviation Agency 1960.

Gainer, C.A. and Rosinia, M.L. The Study of Eye Fixation While Flying Selected Maneuvers using Two Instrument Panels. Martin Engineering Report No. 12,128, June 1962.

Grether, W.F. Discussion of Pictorial Versus Symbolic Aircraft Instrument Displays. USAF Aero Medical Lab. Eng. Division Memo Report TSEAA 694-1E, March 1947.

Jones, R.E., Milton, J.L., Fitts, P.M. Eye Fixations of Aircraft Pilots, I. A Review of Prior Eye-Movement Studies and a Description of a Technique for Recording the Frequency, Duration and Sequences of Eye Fixations During Instrument Flight. USAF AMC TR 5837, September 1949, Pages 1-25.

Jones, R.E., Milton, J.L. and Fitts, P.M., Eye Fixations of Aircraft Pilots, IV. Frequency, Duration and Sequence of Fixations During Routine Instrument Flight. USAF TR 5975, December 1949.

Kelly, F. Equations of Motion of the UH-lA Helicopter for the Dynamic Flight Simulator. Bell Helicopter Company ANIP Technical Report No. D228-380-002 (In press).

Milton, J.L., Jones, R.E., Morris, J.B., and Fitts, P.M. Pilot Reaction Time: The Time Required to Comprehend and React to Contact and Instrument Recovery Problems. AMC TSEAA-694-13a, May 1947.

Milton, J.L., Jones, R.E. and Fitts, P.M. Eye Fixations of Aircraft Pilots II. Frequency, Duration and Sequence of Fixations when Flying the USAF Instrument Low Approach System (ILAS). USAF TR 5839, October 1949.

Milton, J.L., Jones, R.E., and Fitts, P.M. Eye Fixations of Aircraft Pilots V. Frequency, Duration and Sequence of Fixations when Flying Selected Maneuvers during Instrument and Visual Flight Conditions. USAF TR 6018 August 1950.

Milton, J.L., McIntosh, B.B., Cole, E.L. Eye Fixations of Aircraft Pilots VI. Fixations, During Day and Night ILAS Approaches Using an Experimental Instrument Panel Arrangement. AF TR 6570, October 1951.

Milton, J.L., and Wolfe, F.J. Fixations during Zero-reader Approaches in a Jet Aircraft. The eighth of a series of reports on eye fixations of aircraft pilots. WADC TR 52-17, February 1952, Pages 1-15.

Milton, J.L., McIntosh, B.B. and Cole, E.L. Fixations during Day and Night GCA Approaches using an Experimental Instrument Panel Arrangement. The seventh of a series of reports on eye fixations of aircraft pilots. USAF WADC TR 6709, February 1962.

Norden, Division of United Aircraft Corporation. Handbook of Operating and Service Instructions for Vertical Display Generating System (1103 H 0001), April 1963.

Ritchie, M.L. Integrated Instruments: A Drag Indicator, WADC TR 55-423, 1955.

Willis, J.M. Results of Engineering Test Made on the Franklin Institute Dynamic Flight Simulator. Bell Helicopter Company ANIP Technical Report D228-370-001, April 1960.

Willis, J.M. The Role of Motion Information and Its Contribution to Simulation Validity: Description of the Experimental Apparatus. Bell Helicopter Company ANIP Technical Report No. D228-370-005, April 1962.

APPENDICES

APPENDIX A

EQUIPMENT DESCRIPTION OF RANDOM NUMBER GENERATOR

APPENDIX A

Equipment Description - Random Number Generator

In order to control the variables called for by the visual free time study, a master control center and time base generator were designed and built. These two components of the Random Number Generator (see Figure 7) are separately described below.

1. Time Base Generator - A transistorized bi-stable multivibrator is used to determine the duration of each numeral to be displayed to the subject and also to control the time interval between numbers (see Figure 3). The time base generator is housed in the smaller of the two sloping panel cabinets shown. It is necessary to house the generator and control circuitry in separate cabinets in order to ensure that the multivibrator will not be triggered by stray magnetic pickup. A rotary switch on the front of the time generator panel selects one of our display intervals. The positions and their corresponding times are:

Position	Interval (Seconds)
A	1.75
B	1.0
C	0.5
D	0

Regardless of the position of this selector, each numeral is ON for 0.5 second. Power is supplied to the time base generator by a 22.5 volt dry cell battery which is controlled by a toggle switch (ON/OFF) on the front panel.

2. Control Circuitry - Figure 3 shows the control circuitry housed in the larger of the two sloping panel cabinets. Controls and indicators and their related functions are as follows:

a. Warning - This pilot light is wired in parallel with the warning indicators on the vertical display and the standard instrument display. This lamp lights in step with the numerals displayed by the "Nixie Tubes".

b. Numerical Readout Device - For this study only the "units" tube was utilized, therefore, the left-hand and middle tubes were covered. Each individual tube is driven by a rotary stepper switch, the contacts of which are wired to give a predetermined sequence of numbers. The units position relay has forty positions, the tens position relay has fifty positions, and the hundreds position relay has twenty-four positions. Because all three steppers are driven at the same time, a large number of three digit numerals could be displayed before the sequence repeats itself. When using the "units" position digit alone (forty digit sequence), subjects were unable to detect a repetition of the sequence.

c. Stop - This control, when depressed, removes the drive signal to the time base generator which in turn controls the readout devices and warning indicators. Thus it is possible to interrupt a run should this become necessary. This control also actuates a relay which controls the flight simulator analog computer. Depressing the STOP button effectively places the computer into the reset mode.

d. Inst/Vd - This toggle switch controls which numerical readout and warning light combination will be actuated by the random number generator. When the switch is in the INST. position, the "Nixie Tube" and warning lamp on the vertical display side are rendered inoperative. Likewise, when the switch is in the VD position, supply voltages to the indicators on the standard instrument side are removed.

e. Selector - As each numeral is displayed, two other stepper relays are actuated which together count the number of displays presented during one trial. The steppers are so wired that at the end of 80, 120, 200, or 360 displays, an automatic STOP signal is generated. The SELECTOR switch, by its position, determines when the random number generator will be commanded to stop. Position A corresponds to 80 numbers, B to 120 numbers, C to 200 numbers and D to 360 numbers.

f. Reset - The two counting relays described in Paragraph IIC2e above must be manually reset after each run. Depressing the RESET button places the counting circuitry in the zero position for the next trial. Also, the number logic relays described in Paragraph IIC2b do not receive an advance pulse after the last number in a given trial. Therefore, a manual advance signal to these steppers is generated each time the RESET button is depressed.

g. Power - Four different voltages are required for the operation of the random number generator: +28 VDC, +300 VDC, 115V 60 CPS, and +22.5 VDC. The first three of these voltages are controlled by the two POWER toggle switches.

h. Next Number - When this button is depressed the number display on the master control center comes on in advance of the next display command signal. Numeral displays in the dynamic cabin do not come on when this button is depressed. Thus, the experimenter may monitor the up-coming number. This button is also used at the start of each trial to assure that the number logic relays are indeed in the zero position.

i. Start - When this button is depressed, a latching relay is energized which in turn supplies a drive command signal to the time base generator. This signal remains present until the STOP button is depressed or the automatic stop signal is generated.

3. Calibration

a. Frequency of Calibration - In order to assure accuracy to within ±.1%, the calibration procedure described in IIC3b is performed on a daily basis.

b. Procedure -

(1) Disconnect Random Number Generator from Master Control Panel.

(2) Select program D on the time base generator and the control panel.

(3) Depress START button on control panel.

(4) Adjust R_D on the rear panel of the time base generator for minimum inter-display time consistent with proper relay action.

(5) Adjust R_2 for 180 seconds ±.2 sec. program duration.

(6) Select programs A on both panels of the Random Numbers Generator.

(7) Adjust R_A for 180 seconds ±.2 sec. program duration.

(8) Repeat steps (6) and (7) for programs B and C using R_B and R_C respectively.

4. Analog Computer Setup

1. Equations of Motion - The analog computer is programmed to reproduce the response characteristics of the UH-1 helicopter.

2. Scoring

a. Conversion Factors for Absolute Integrated Error - Four flight characteristics are measured for this study. Conversion factors for absolute error scores are as follows:

(1) Airspeed: 1 knot error for one second is equal to 0.834 volts.

(2) Altitude: 1 foot error for one second is equal to 0.0163 volts.

(3) Heading: 1 degree error for one second is equal to 0.735 volts.

(4) Lateral Deviation: 1 foot error for one second is equal to 0.24 volts.

b. Scoring Circuitry - Figure 4 shows the interconnections between the system and the scoring circuits used to evaluate subject response.

5. Calibration (See Figure 4)

A separate calibration is performed daily on the system and on the scoring circuits. The system checkout is initiated by placing the operate/calibrate switch in the calibrate position and the pulse/score switch in the pulse position. (NOTE: During calibration, the hydraulic power to the platform is removed.) The setting of these two switches (a) removes the normal pilot inputs (cyclic, collective and yaw) and substitutes in their place a standard calibrating pulse (a charge capacitor discharging at a predetermined rate). When the Reset/Compute switch is placed in the computer position, this calibrating pulse drives the various computer channels at predetermined ratio. The calibrating run lasts for 10 seconds after which the computer outputs (which are recorded on a Sanborn recorder) are compared with a known response curve. In this manner, any malfunction in the rotor pitch, aircraft pitch, aircraft roll, V_x, V_e, heading, torque or altitude channel will be detected.

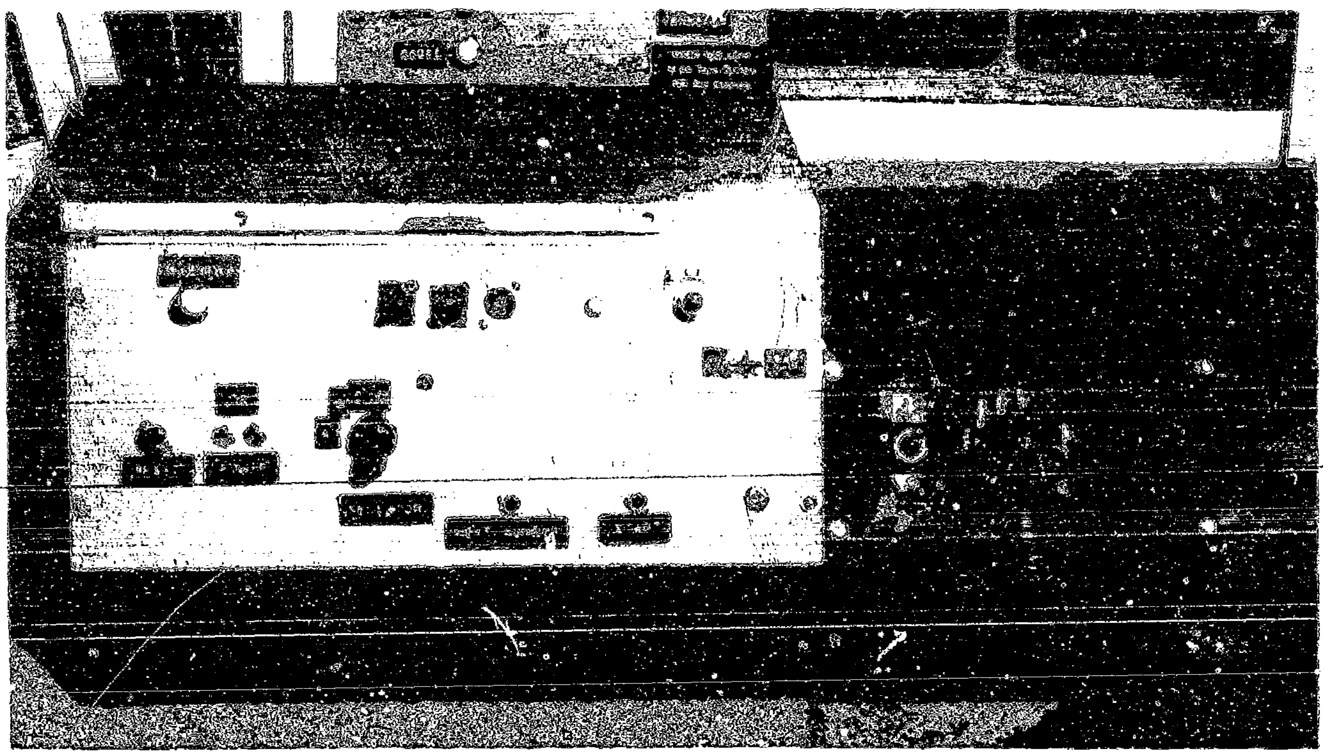
To initiate the scoring calibration sequence, the operate/calibrate switch is placed in the score position. This applies a fixed voltage in place of the normal pilot inputs. The system is then placed in the compute condition for 60 seconds and error scores are allowed to accumulate on the scoring circuits. At the end of this run, the readings of the heading, altitude, left deviation, right deviation, airspeed and time counters are compared against known correct readings.

It is important that the system check be performed and found acceptable before beginning the scoring circuit test inasmuch as the computers drive both the strip recorder and the scoring integrators.

6. Method of Programming Airspeed

Airspeed displayed on the standard instrument panel was velocity along the pathway.

7. Sensitivity of Pathway Deviation Meter - Pathway deviation on the standard instrument panel is indicated on an ILS instrument (ID 453). The sensitivity of this instrument is adjusted so that full deflection of the vertical needle (left or right deviation) is equal to 300 feet of deviation. Full deflection of the horizontal needle (vertical deviation) is produced by an altitude error of 100 feet. These sensitivities could have been adjusted to any other setting. The optimum values of sensitivity were determined during the pretest evaluation period. This lateral deviation was chosen to be identical with maximum deviation of the pathway on the VD display.



Random number generator

APPENDIX B

INSTRUCTIONS TO Ss - TRAINING TRIALS

APPENDIX B

Instructions to Ss - Training Trials

You are about to participate in a study to help us determine which of two aircraft display systems provides the pilot with the most visual free time while "flying" a command heading, altitude and airspeed. The two display systems are installed on the left and right sides of the dynamic simulator and are identical with respect to control input and system output. The difference exists in the means of displaying the simulated aircraft's situation. In one case, standard aircraft instrumentation is used to display the aircraft's situation. In the other case, the same information is presented on the JANAIR vertical display. In the course of the experiment you will be asked to perform the same task on both display systems.

(If S is trained on instruments first read)

You will notice that the instrument panel is composed of six standard aircraft instruments. These include an airspeed indicator, an altimeter, a compass, an attitude indicator, a rate of climb meter and a position indicator. During each trial your task will be to maintain 0-degree heading, 80 knots airspeed and 1,000 feet altitude. The task will include correcting for flight path deviations using the position indicator.

(If S is trained on vertical display first read)

You will notice that the instrument panel is composed of a TV screen displaying an encoded representation of the real world with a pathway. The pathway is situated at a 1000 foot altitude on a 0-degree heading. Tarstrips on the path are spaced every 30 feet. The rate at which they are passing under you and the pitched down attitude of the ship (indicate) represents 80 knots airspeed. During each trial your task will be to maintain 1000 feet altitude, 0-degree heading, and 80 knots airspeed. The task will include correcting for flight path deviations using the position indicator.

TO FOLLOW PRECEDING INSTRUCTIONS.

Each trial will last for three minutes. Prior to the trial you will be given a chance to position the cyclic, collective and pedal controls to maintain 80 knots, 1000 foot altitude and 0-degree heading. There will be a gust or forcing function to require you to make constant corrections in the tracking task.

The first few trials may be regarded as training trials. You are asked to perform your best on each trial; however, do not be concerned if at first you do not perform the task with a high level of proficiency.

During the training sessions you will have an opportunity to practice the tracking task on both displays until your performance meets a criterion we have established for each display system.

APPENDIX C

INSTRUCTIONS TO Ss - TEST TRIALS

APPENDIX C

Instructions to Ss - Test Trials

On a nixie tube located at the lower right side of the instrument panel we are capable of displaying digits at various rates. There are four rates at which these digits appear. (Present each rate to S for 30 seconds and ask him to read them). During the next series of trials you will be required to read each digit that appears on the nixie while "flying" the tracking task you have learned, i.e., holding 1000 feet altitude, 80 knots airspeed and 0-degrees heading. It is important that you read each and every number that appears during the trial. Our ability to utilize your data depends upon our knowing that you have read every digit.

Prior to the commencement of each trial, I will indicate the rate at which the digits will appear. The rate will remain constant throughout the three minute trial. At the presentation of each digit a light will be illuminated just above the nixie tube to indicate that digits are being displayed.

Let me repeat, you must at all costs read each and every number at the rate they appear regardless of the produced effort upon your tracking performance. Otherwise, we will be unable to utilize the data.

Any questions before we start?

APPENDIX D

SUMMARIES OF ANALYSIS OF VARIANCE

TABLE I

SUMMARY OF ANALYSIS
OF VARIANCE FOR ALTITUDE

Source	SS	df	MS	F	P
Displays	10,099.05	1	10,099.05	5.45	
Rates	95,377.19	4	23,844.30	12.86	.01
D X R	6,773.20	4	1,693.30	.91	
Residual	352,234.86	190	1,853.97		
Total	464,504.30	199			

TABLE II

SUMMARY OF ANALYSIS
OF VARIANCE FOR HEADING

Source	SS	df	MS	F	P
Displays	31,588.41	1	31,588.41	52.27	.01
Rates	45,506.64	4	11,376.66	18.83	.01
D X R	34,385.40	4	8,596.35	14.23	.01
Residual	114,812.89	190	604.27		
Total	226,293.34	199			

TABLE III

SUMMARY OF ANALYSIS
OF VARIANCE FOR AIRSPEED

Source	SS	df	MS	F	P
Displays	5,150.68	1	5,150.68	15.61	.01
Rates	36,974.39	4	9,243.60	28.08	.01
D X R	14,201.76	4	3,550.44	10.76	.01
Residual	62,698.87	190	329.99		
Total	119,025.70	199			

TABLE IV

SUMMARY OF ANALYSIS
OF VARIANCE FOR TRACK

Source	SS	df	MS	F	P
Displays	55,898.31	1	55,898.31	532.11	.01
Rates	10,024.41	4	2,506.10	23.86	.01
D X R	492.91	4	123.23	1.76	
Residual	19,958.72	190	105.05		
Total	86,374.35	199			

TABLE V

SUMMARY OF ANALYSIS
OF VARIANCE FOR COMBINED SCORES

Source	SS	df	MS	F	P
Displays	1,224,990	1	1,224,990	8.966	.01
Rates	4,704,133	4	1,176,033	8.607	.01
D X R	7,770,868	4	1,942,717	14.219	.01
Residual	25,958,922	190	136,626		
Total	39,658,913	199			

APPENDIX E

SUMMARIES OF MULTIPLE RANGE TEST

TABLE I

DUNCAN'S TEST APPLIED TO MEAN AIE OF ALTITUDE FOR FIVE READING RATES

Means	B 238 9	C 323.9	D 926.6	E 1250.7	Shortest Significant Range
A 155.4	83.5	168.5			R_2 = 343.25
B 238.9		85.0			R_3 = 358.34
C 323.9			602.7	926.8	R_4 = 367.77
D 926.6				324.1	R_5 = 375.31

A = 0 presentation of digits per 3 minute trial
B = 80 presentation of digits per 3 minute trial
C = 120 presentation of digits per 3 minute trial
D = 200 presentation of digits per 3 minute trial
E = 360 presentation of digits per 3 minute trial

When $R_i \leq \overline{X}_1 - \overline{X}_2$ then H_o is rejected at the .01 level of confidence.

TABLE II

DUNCAN'S TEST APPLIED TO MEAN AIE OF HEADING FOR FIVE READING RATES UNDER SI AND VD

Means	A 320	B 335	C 344	D 808	E 935	F 1061	G 1115	H 1545	I 3419	J 8422	Shortest Significant Range
A 320		15	24								R_2 = 270.82
B 335			9								R_3 = 281.23
C 344				464	591	717					R_4 = 290.16
D 808					127	253	307				R_5 = 296.11
E 935						126	180				R_6 = 300.58
F 1061							54				R_7 = 304.30
G 1115								430			R_8 = 308.02
H 1545									1874		R_9 = 310.25
I 3419										5003	R_{10} = 312.48
J 8422											

A = VD-80 presentation of digits per 3 minute trial
B = VD-0 " " " " " " "
C = VD-120 " " " " " " "
D = VD-360 " " " " " " "
E = SI-0 " " " " " " "
F = VD-200 " " " " " " "
G = SI-80 " " " " " " "
H = SI-120 " " " " " " "
I = SI-200 " " " " " " "
J = SI-360 " " " " " " "

When $R_i \leq \overline{X}_1 - \overline{X}_2$ then H_o is rejected at the .01 level of confidence.

TABLE III

DUNCAN'S TEST APPLIED TO MEAN AIE OF AIRSPEED FOR FIVE READING RATES UNDER SI AND VD

Mean	A 684	B 1047	C 1184	D 1211	E 1325	F 1437	G 2117	H 2482	I 3532	J 6619	Shortest Significant Range
A 684		362	499	525							$R_2 = 202.02$
B 1047			137	164	278						$R_3 = 209.79$
C 1184				27	141	273					$R_4 = 216.45$
D 1211					114	226					$R_5 = 220.89$
E 1325						112					$R_6 = 224.22$
F 1437							680				$R_7 = 227.00$
G 2117								365			$R_8 = 229.77$
H 2482									1050		$R_9 = 231.44$
I 3532										3087	$R_{10} = 233.10$
J 6619											

A = SI-0 Presentations of digits per 3 minute trial.
B = SI-80 " " " " " " "
C = VD-0 " " " " " " "
D = VD-80 " " " " " " "
E = VD-120 " " " " " " "
F = SI-120 " " " " " " "
G = VD-200 " " " " " " "
H = VD-360 " " " " " " "
I = SI-200 " " " " " " "
J = SI-360 " " " " " " "

When $R_i \leq \overline{X}_1 - \overline{X}_2$ then H_o is rejected at the .01 level of confidence.

TABLE IV

DUNCAN'S TEST APPLIED TO MEAN AIE OF TRACK FOR FIVE READING RATES UNDER SI AND VD

Mean	A 558	B 726	C 782	D 1896	E 2241	F 3378	G 4298	H 4497	I 5160	J 5589	Shortest Significant Range
A 558		168	224								R_2 = 113.93
B 726			56								R_3 = 118.31
C 782				1114							R_4 = 122.07
D 1896					345						R_5 = 124.57
E 2241						1137					R_6 = 126.45
F 3378							920				R_7 = 128.02
G 4298								199			R_8 = 129.58
H 4497									663		R_9 = 130.52
I 5160										429	R_{10} = 131.46
J 5589											

A = VD-0 presentations of digits per 3 minute trial
B = VD-120 " " " " " " "
C = VD-80 " " " " " " "
D = VD-200 " " " " " " "
E = VD-360 " " " " " " "
F = SI-0 " " " " " " "
G = SI-80 " " " " " " "
H = SI-120 " " " " " " "
I = SI-200 " " " " " " "
J = SI-360 " " " " " " "

When $R_i \leq \overline{X}_1 - \overline{X}_2$ then H_o is rejected at the .01 level of confidence.

TABLE V

DUNCAN'S TEST APPLIED TO THE COMBINED ERROR FOR FIVE READING RATES UNDER SI AND VD

Mean	A 114	B 137	C 147	D 234	E 308	F 325	G 382	H 425	I 721	J 1200	Shortest Significant Range
A 114		23									299.2
B 137			10								312.4
C 147				87							320.6
D 234					74						327.2
E 308						17					332.1
F 325							57		396		336.2
G 382								43	339		340.3
H 425									296		342.8
I 721										479	346.1
J 1200											

A = VD-0 presentations of digits per 3 minute trial.
B = VD-80 " " " " " " "
C = VD-120 " " " " " " "
D = SI-0 " " " " " " "
E = SI-80 " " " " " " "
F = VD-200 " " " " " " "
G = SI-120 " " " " " " "
H = VD-360 " " " " " " "
I = SI-200 " " " " " " "
J = SI-360 " " " " " " "

When $R_i \leq \bar{X}_1 - \bar{X}_2$ then H_o is rejected at the .01 level of confidence.

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